**Title Page**

**Title:** Auto-Regulated Resistance Training: Does Velocity-Based Training Represent the Future?

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## Abstract

Traditionally, resistance training intensity has been based upon a percentage of an individual's 1RM. However, there are numerous shortcomings with this approach, including its failure to consider an athlete's conditional, day-to-day training readiness. In order to address these limitations, the use of various progressive auto-regulated resistance training protocols has been suggested in the literature. Recent advances in the monitoring of movement velocity offer a unique approach by which to optimise the use of auto-regulated resistance training. By matching established acute resistance training variables to specific movement velocities the strength and conditioning practitioner can optimise resistance training intensity and objectively identify the onset of neuromuscular fatigue.

**Key Words:** Resistance Training; Auto-Regulation; Velocity-Based Training

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## Introduction

Resistance training (RT) is considered a key training stimulus for improving maximal strength, rate of force development (RFD), power output and subsequent athletic performance potential. However, physiological adaptations as a result of RT are highly dependent upon the training prescription and subsequent dose-response (26,26). It has traditionally been assumed that RT should be performed to muscular failure to provide an adequate overload for maximal strength gains. However, recent evidence suggests training to failure does not produce superior gains in strength and may in fact be counter-productive (5,25,26). With this in mind, there is a general consensus within both the scientific literature and strength and conditioning communities that proper manipulation of several acute training variables, including intensity (load), volume (repetitions x sets), recovery time between sets, exercise type and order, is required to ensure sufficient loading, prevent overtraining and optimise strength gains (8,20,25,26,28).

Of the aforementioned training variables, intensity and volume are arguably the most important when it comes to determining the type and magnitude of neurological and morphological adaptations that occur as a result of RT. Typically, high intensity, low volume RT is performed to develop maximal strength and RFD. Whereas, lower intensity, high volume RT is performed to elicit muscle hypertrophy and enhance work capacity (8,20,25,26,28). Resistance training intensity is characteristically based upon a percentage of an individual's one-repetition maximum (1RM) in a given exercise such as the back squat, deadlift or bench press. Whereas, RT volume is usually quantified by multiplying the load by the number of repetitions and sets performed (volume load = load x repetitions x sets).

While the quantification of RT volume is relatively simple, the accurate monitoring and quantification of RT intensity has proved somewhat more elusive. The establishment of 1RM is typically done via either direct 1RM assessment or the performing of multiple repetitions to failure to estimate 1RM via a series of predication equation tables (14). The use of 1RM percentages to dictate strength training loads has been questioned by several authors (17,19,21). Indeed, multiple shortcomings can be identified with the traditional 1RM percentage-based approach. Firstly, it requires the direct assessment of 1RM, which may increase the likelihood of injury if performed incorrectly by novice athletes. Secondly, strength levels can change quite rapidly requiring frequent testing to ensure the optimal training load. Thirdly, 1RM testing can be quite time consuming and impractical for large groups of athletes.

Arguably, the biggest issue with the use of 1RM percentages is that it represents a rather arbitrary approach to training loads, as it fails to consider an athlete's conditional readiness to train on a daily basis. An athlete's conditional, day-to-day training readiness can be influenced via numerous factors such as biological variability, accumulated fatigue, nutrition, sleep and general life style stressors (16,32). As stated by the late Mel Siff (32) "the use of numerical computations as sole descriptor of loading often overlooks the fact that apparently objective measures like this do not take into account an athlete's subjective perception of the intensity and overall effects of loading". Therefore, it can be argued that the use of 1RM percentages to dictate RT intensity may represent a sub-optimal approach by which to develop strength.



**Progressive Auto-Regulating Resistance Training**

In order to address the aforementioned limitations of the traditional percentage-based approach, several authors have proposed the use of various progressive auto-regulating RT protocols (6,18,22,33). Auto-regulated RT can be defined as a form of daily-undulating periodization that adjusts to an athlete's conditional, day-to-day training readiness (33). Because individuals respond to training stimuli at varying rates, the use of auto-regulated RT allows athletes to adjust the training intensity on a daily basis dependent upon their given level of performance and the impact of neuromuscular fatigue (33). The use of an auto-regulated approach towards RT was first reported in the literature by DeLorme (6), who suggested a protocol of multiple 10 RM sets. DeLorme refined the system to include three progressively heavier sets of 10 repetitions and referred to the program as progressive resistance exercise (PRE). This was developed further by Knight (18), who modified De Lorme's original PRE-protocol to create a system known as daily auto-regulated resistance exercise (DAPRE).

Within the DAPRE system, RT intensity is based upon an estimated 6RM load commonly known as the working weight. During set one, 10 repetitions at 50% of the estimated working weight are performed. This is then followed by 6 repetitions at 75% of the estimated working weight for set two. During the third set, the exercise is performed to form failure at 100% of the estimated working weight with the total number of repetitions completed used to determine the subsequent training load for the fourth set. Ideally, one will be able to complete 6 repetitions when working to failure. If more than 6 repetitions can be completed the weight must be increased. Conversely, if less than 6 repetitions are achieved, then the load is too heavy and must be decreased. The same approach is then used during the fourth set with the total number of repetitions completed being used to determine the working weight for the next training session. The utility of the DAPRE system is somewhat limited as there is little variation in the acute RT variables. Therefore, training accommodation and stagnation may occur over the longer term. Based upon this observation, Siff (33) proposed a system known as auto-regulating progressive resistance exercise (APRE). Similar to DAPRE, the goal during the third set of APRE is to establish a RM working weight. However, APRE employs varying loading protocols dependent upon the focus of a specific training session (Table 1). For maximum strength and RFD there is APRE 3RM, for strength APRE 6RM, and for hypertrophy APRE 10RM.

**(Insert Table 1)**

To date only one study has examined the effectiveness of APRE. Mann et al. (22) demonstrated that in comparison to a linear periodisation (LP) training programme with set increases in RT intensity each week, APRE resulted in significantly greater gains in back squat 1RM (APRE 19.6 ± 20.28 kg vs. LP 3.79 ± 15.8 kg, $p$ = < 0.02), bench press 1 RM (APRE 9.52 ± 10.49 kg vs. LP 5.05 ± 0.4 kg, $p$ = <0.05) and bench press repetitions to failure at 102 kg (APRE 3.17 ± 2.86 vs. LP -0.009 ± 2.4 repetitions; $p$ = <0.02) over a 6-week training period. Theoretically, the utility of APRE could be developed further via the use of repetition zones matched with appropriate volume and rest parameters established from a synthesis of current RT variable recommendations (Table 2) (25,26,28). Similar to the standard APRE protocol, a working weight could be established during the third set. However, this load would subsequently be maintained for further sets in line with the planned training session variables.

**(Insert Table 2)**

**Velocity-Based Resistance Training**

Several authors have proposed that the monitoring of movement velocity may allow for more precise and objective quantification of RT intensity (11,16,23,29). Movement velocity can now be easily and accurately measured using commercially available linear position transducers, rotary encoders and accelerometer-based technologies (16). Consequently, the monitoring of movement velocity in a gym setting is now far more feasible, making the application of velocity-based RT a more viable proposition. Several authors have proposed that movement velocity may be a more sensitive and accurate indicator of relative intensity than the traditional 1RM percentage-based approach (11,13). This is based upon the observation of a strong linear relationship between movement velocity and %1RM in exercises such as the back squat (7,31); bench press (10,11,15,30);

prone bench pull (30); leg press (7); pull up (2) and overhead press (1). The mean concentric velocity produced during a successful 1RM lift is commonly known as the movement velocity threshold (MVT). Interestingly, MVT and %1RM movement velocities have been shown to remain relatively consistent even when absolute strength increases (11,23). Therefore, it is possible to create a movement velocity profile and with some precession, determine RT loads based upon a given movement velocity (Figure1).

**(Insert Figure 1)**



Movement velocity has also been suggested to be a valid, objective and practical indicator of neuromuscular fatigue (29). Neuromuscular fatigue is a complex multi-factorial phenomenon that typically results in a reduction in force-generating capability, muscle fibre shortening velocity and power output (9). Resistance training elicits both mechanical and metabolic stress, resulting in the onset of neuromuscular fatigue (9,29). Several studies have shown that as the number of repetitions increases, neuromuscular fatigue develops, and movement velocity slows (3,4,12,13,24,29). Interestingly, MVT also appears to be the speed at which exercise specific, muscle failure will occur when repetitions to failure are performed irrespective of the relative load (16). Fundamentally, the load lifted during RT directly corresponds to the number of repetitions that can be performed due to the inverse relationship between load and volume. Therefore, it is important to monitor the impact of RT volume as it will directly affect the intensity of RT that can be performed and vice versa.

Given that movement velocity can accurately predict RT intensity and act as an objective indicator of neuromuscular fatigue, it is proposed that the use of velocity-based RT may allow for the optimal auto-regulation and individualisation of RT intensity and volume dependent upon, not only the desired training outcome, but also an athlete's conditional, day-to-day training readiness. Although 1RM may fluctuate over time, MVT and %1RM movement velocities have been shown to remain relatively consistent (11,23). Therefore, in order to optimise RT intensity and control the impact of neuromuscular fatigue, velocity bands and/or velocity stops can be set based upon an individual's load-velocity profile. These can then be matched to appropriate repetition zones established from a synthesis of current acute RT variable recommendations (25,26,28) to ensure the optimal training stimuli.

For example, let's assume that an athlete presents with a bench press 1RM of 200 kg and an MVT of 0.15 m/s. If the objective of the training session is to enhance maximal strength, a RT intensity of 90% 1RM (e.g., 180 kg x 3 repetitions x 3 sets ) would be prescribed using the traditional percentage-based method. However, this represents a relative arbitrary approach that does not consider the athlete's conditional, day-to-day training readiness, nor the impact of neuromuscular fatigue. If using movement velocity, an athlete could be prescribed a RT intensity based upon a set velocity band that equates to 90 - 95% 1RM (e.g., 3 repetitions at a movement velocity of between 0.20 – 0.25 m/s). Alternativity, a velocity stop may also be used (e.g., when movement velocity drops below 0.20 m/s). If the velocity band or stop is exceeded, then the load would be increased until the movement velocity meets the required speed. Conversely, if the speed of movement drops below the set velocity band or stop then the load could be reduced, or the set terminated.

In addition, to optimising RT intensity and volume, monitoring of movement velocity enables immediate, real-time, performance feedback which research suggests may enhance physiological adaptations to RT and motivate athletes to apply consistent maximal effort (27). Training with the intent to move as load a fast as physically possible is believed to enhance neurological adaptations to RT such as motor unit recruitment, firing frequency, inter/intra muscular coordination and corticospinal excitability (8). All of which have been shown to enhance maximal strength, RFD, and power output. Additionally, the provision of real-time, movement velocity information has been suggested to help motivate athletes to increase their speed of movement by providing a bench mark with which to compare their own past performance and that of others. This knowledge of results may motivate athletes to improve their own performance while competing against others, which in turn will help drive consistent maximal intent during every repetition, set and training session (23).

**Velocity Based Auto-Regulated Resistance Training**

Several studies have demonstrated that the use of movement velocity to dictate RT intensity can elicit significant gains in maximal strength and athletic performance potential (3,4,12,23). Given the potential advantages of velocity-based RT, its combination with an auto-regulated type approach may enable the optimisation of a RT stimuli dependent upon the set training programme objectives and day-to-day fluctuations observed in an athlete's conditional training readiness. For example, the first set of a RT prescription could be performed at maximal velocity with the load either increased, maintained, or reduced for subsequent sets dependent upon the pre-determined movement velocity band/stop. Training loads could then be adjusted for subsequent sets, enabling a more precise and objective quantification of RT intensity. Another more novel approach to velocity-based RT may be rather than performing a pre-determined fixed number of repetitions, training volume could be set based on the magnitude of velocity loss, with a set terminated when a given percentage of velocity loss (e.g., 10, 25 or 50%) has been reached (13). For example, to develop maximal strength and RFD, a minimal velocity loss (e.g., 5%) would be desirable. Whereas, a greater velocity loss (e.g., 50%) would be targeted to elicit a sufficient amount of mechanical and metabolic stress in order to promote muscle fibre hypertrophy or enhance work capacity.



**Auto-Regulated Resistance Training Considerations**

Whilst velocity-based loading offers a unique way by which to optimise RT intensity, there are several important considerations that must be considered. Firstly, MVT is both individual and exercise-dependent; thus, the same absolute velocity will represent different training intensities dependent upon the individual and the selected exercise. Secondly, when measuring movement velocity, it is important to consider whether the measurement of mean or peak velocity is more suitable. The use of mean concentric velocity is seen as a more stable metric during non-ballistic strength exercises such as the bench press and back squat (15). Conversely, the measurement of peak velocity has been proposed to be more suitable when determining the load of ballistic weightlifting movements (e.g., snatch and clean and jerk) and their derivatives. This is due to the fact that the attainment of a high peak bar velocity is a key variable in determining whether a lift is successful or not (23,34).

Whilst velocity-based RT training may enable a more precise and objective quantification of RT intensity dependent upon at athlete's conditional, day-to-day training readiness, there does exist several shortcomings with its use. One-repetition maximum testing will still initially be required when using velocity-based loading in order to establish exercise specific MVT. However, exercise specific MVT has been demonstrated to remain relatively consistent despite increases in maximal strength (11,23). Therefore, 1RM testing would be required considerably less than when using the traditional percentage-based approach. The cost of technology to accurately and reliably measure movement velocity can also be seen as another limiting factor. However, the cost of linear position transducers, rotary encoders and accelerometer-based technologies has dropped considerably in recent years, although this is still likely to remain a limitation for many strength and conditioning practitioners. Finally, further research is required to investigate the long-term efficacy of a velocity-based, auto-regulatory approach towards RT.



**Conclusion**

Intensity and volume are arguably the most important acute RT variables. Traditionally, RT intensity has been based upon a percentage of an individual's 1RM. However, there are numerous shortcomings with this approach, including its failure to consider an athlete's conditional, day-to-day training readiness. In order to address these limitations, the use of various progressive auto-regulated

RT protocols has been suggested. Current, auto-regulated RT systems such as PRE, DAPRE and APRE are dependent upon the performance of repetitions to muscular failure in order to identify the required training load for subsequent sets. Furthermore, there is little variation in the acute training variables within these systems, that may result in training accommodation and stagnation. Recent advances in the monitoring of movement velocity offer a unique approach by which to optimise the use of auto-regulated RT. By matching established acute RT variables (e.g., repetitions, sets, recovery time etc) to specific movement velocities, the strength and conditioning practitioner can optimise RT intensity and objectively identify the onset of neuromuscular fatigue. Monitoring of movement velocity also provides real-time, performance feedback, which evidence suggests may enhance neurological adaptations to RT and improve an athlete's motivation to apply consistent maximal effort. In summary, the monitoring of movement velocity may allow for the true auto-regulation and individualisation of RT, which is arguably key to optimising strength gains and improving an athlete's physical performance potential.

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**Table 1.**

Auto-Regulating Progressive Resistance Exercise (APRE) Protocol (33)

| Set | 10 RM Hypertrophy Routine | 6 RM Strength Routine | 3 RM Maximal Strength Routine |
|---|---|---|---|
| **1** | 12 Reps / 50% 10RM | 10 Reps / 50% 6RM | 6 Reps / 50% 3RM |
| **2** | 10 Reps / 75% 1RM | 6 Reps / 75% 6RM | 3 Reps / 75% 3RM |
| **3** | Reps to failure / 10RM | Reps to failure / 6RM | Reps to failure / 3RM |
| **4*** | Adjusted reps to failure | Adjusted reps to failure | Adjusted reps to failure |

* Load increased by 2.5 – 5 kg for every 2 reps above or alternatively reduced by 2.5 – 5 kg for every 2 repetitions below the target RM.

**Table 2.**

Synthesis of Recommended Resistance Training Load Variables (25,26,28)

| | Strength Endurance | Hypertrophy | Maximal Strength | Explosive Strength |
|---|---|---|---|---|
| **Intensity** | 0 – 70% 1RM | 70 – 80% 1RM | 80 – 90% 1RM | 0 – 80% RM |
| **Repetition Range** | +12 | 12 – 9 | 8 – 5 | 4 – 1 |
| **Set Range** | 4 – 5 | 4 – 6 | 4 – 7 | 4 – 8 |
| **Recovery (Mins)** | >00:30 | >02:00 | >03:00 | >03:00 |

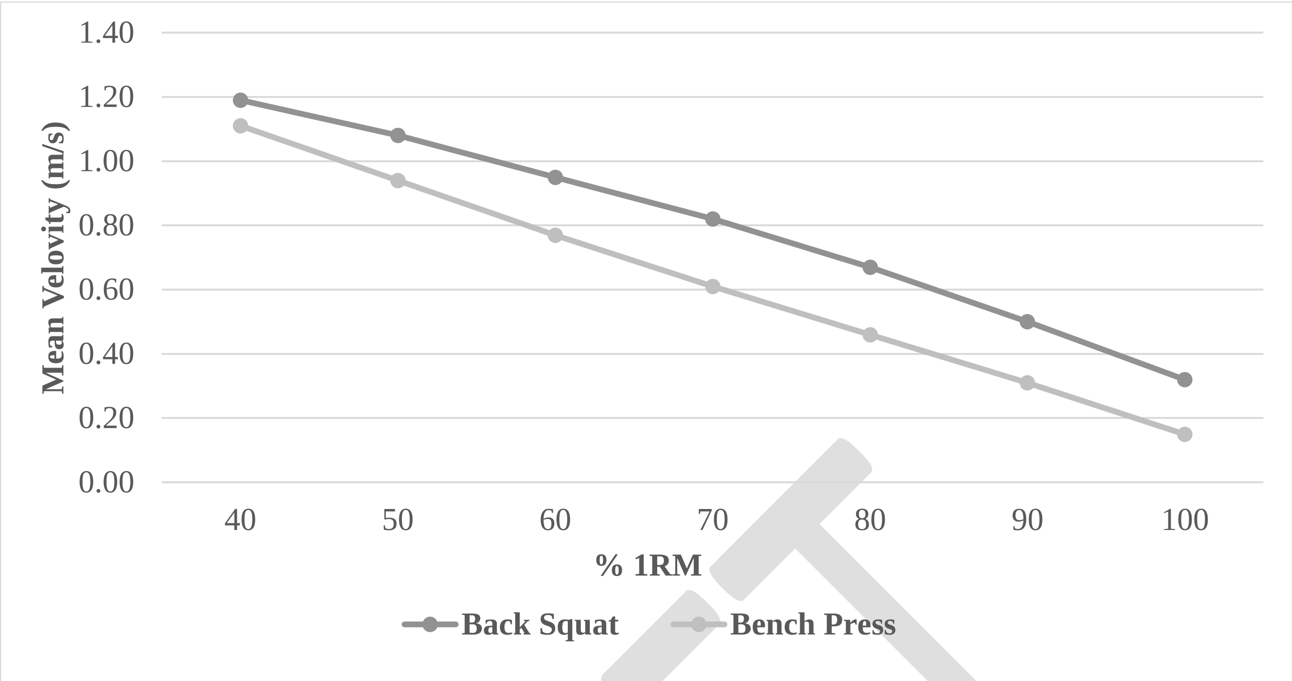


**Figure 1.** Example of Different Load-Velocity Profiles for the Back Squat and Bench Press Exercises (16).